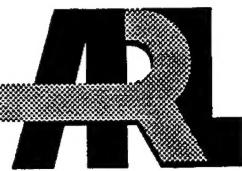


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## **Plastic Encapsulated Microcircuit Reliability and Cost Effectiveness Study**

Douglas Emerson  
Edward Hakim  
Anand Govind

ARL-TR-939

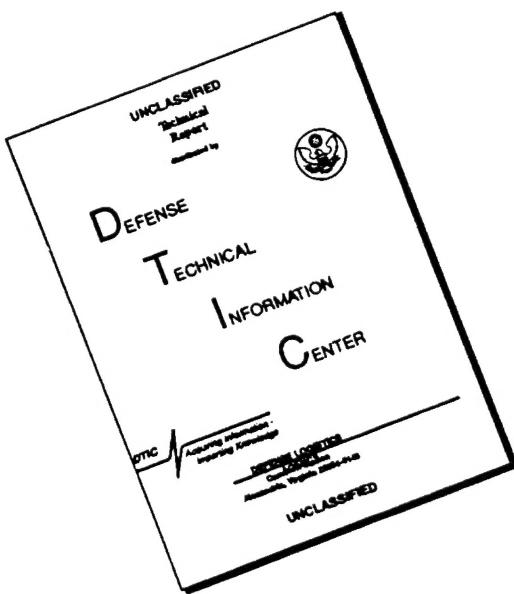
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## CONTENTS

	<u>Page</u>
<b>ABSTRACT .....</b>	iv
1. INTRODUCTION (and Acronyms and Abbreviations).....	1
2. STUDY OBJECTIVE.....	1
3. COST COMPARISON .....	3
4. OPERATING LIMITS OF THE SYSTEM.....	3
5. REQUIREMENTS ASSURANCE.....	4
5.1 First Article Testing .....	4
5.2 Reliability Demonstration Testing.....	5
5.3 Operational Testing.....	5
6. FAILURE DIAGNOSTICS METHOD .....	5
7. FAILURE ANALYSIS RESULTS.....	6
<b>REFERENCES .....</b>	6

## TABLES

1. PLGR PEM and Cost Comparison With HCEM.....	2
2. PLGR Environmental Requirements .....	3
3. First-Article Reliability-Test Summary.....	4

## Plastic Encapsulated Microcircuit Reliability and Cost Effectiveness Study

**ABSTRACT**—This study evaluates the reliability and cost-effectiveness of using commercial plastic-encapsulated microcircuits (PEM) in a typical military system, with a view to increasing their acceptability in military applications. The cost comparison indicates an average 6-fold decrease in cost when commercial devices are used. Assurance testing did not reveal any special problems with commercial parts. Thus, if commercial PEM were proven to be sufficiently reliable for an intended military application, large cost savings would be gained by using them instead of hermetic packages.

The 4.5-sigma *enhanced inspection* program and the process control methods suggested here would enhance the manufacturing yield of the PLGR (precision lightweight global positioning system receiver) by encouraging improvements in the manufacturing process while simultaneously cutting the cost of a 100% rescreen to qualify the final product. Neither the requirements assurance tests (including the step-stress test-analyze-and-fix test), nor the reliability demonstration test, nor the operational test, showed more failures than are typical for any new development, and no problems unique to PEM were observed. Thus, the use of PEM did not lead to any special problems that caused PLGR-use specifications to be violated.

Complete failure analysis of the isolated parts is in progress, and the results will help to understand the specific reliability issues involved in the use of PEM in military systems. These issues can then be addressed to improve the acceptability of such devices in future military applications.

## 1. INTRODUCTION

### *Acronyms and Abbreviations \**

ASIC - Application Specific Integrated Circuit  
CACD - Collins Avionics and Communication Division  
DoD - US Department of Defense  
DIP - dual in-line package  
HAST - highly accelerated stress test  
HCEM - hermetic ceramic-encapsulated microcircuit (military specs)  
MIL - military  
MTBF - mean time between failures  
MTBOMF - mean time between operational mission failures  
NDI - non-development item  
PEM - plastic-encapsulated microcircuit (commercial specs)  
PLGR - Precision Lightweight Global Positioning System Receiver  
SPC - statistical process control  
TAAF - test analyze and fix  
USG - US Government (but non-DoD)

PEM offer major advantages in cost, size, weight, performance, and market lead-time; thus they have attracted 99% of worldwide microcircuit sales and are being used, for example, in automotive, computer, and avionics applications. However, the DoD and USG still require HCEM, despite their high cost and low reliability compared with PEM. Due to large cuts in spending, the interest in using PEM has been increasing in the USG and DoD agencies. Moreover, outdated USG and DoD standards and handbooks on the manufacture and use of HCEM have prompted a fresh look at the field reliability data for PEM, preparatory to increasing their acceptability for military applications. Ref. [3] discusses in more detail the reliability and cost issues associated with PEM.

## 2. STUDY OBJECTIVE

The objective of this study was to assess PEM used in military environments and to determine the failure mechanisms associated with their field performance. The study was conducted by CACD for the Army Research Laboratory (ARL), Fort Monmouth (Contract No. DAAL01-94-C-3443) using the PLGR as a test system. The PLGR is a lightweight, handheld, precision global positioning system receiver selected by the DoD for portable, moderate dynamic applications. CACD was selected as the supplier through a NDI competition in 1992. Over 25k units purchased by the DoD Joint Program Office since 1993 September are in service in applications for the US Army, Air Force, Navy, Marines, Dep't of Agriculture, National Security Agency (NSA), and at some international locations. Each unit has a 6-year warranty. All warranty returns are sent to the CACD manufacturing site in Iowa.

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\* The singular and plural of an acronym are always spelled the same.

In addition to maintaining the performance of predecessor units and appreciably reducing the size, the cost reduction was among the most important design considerations. To this end, the PLGR uses PEM. The system has 406 electrical parts. The microcircuits, transistors, and diodes are almost entirely surface-mounted PEM. Table 1 details the type and quantity of PEM in the PLGR. Three parts (marked with an asterisk) are considered proprietary, and procurement and cost data are not available for them. However, failure analysis data and failure rate calculations were derived for all the parts listed.

TABLE 1  
PLGR PEM and Cost Comparison with HCEM

PEM Part Description	PEM Supplier (Alternate Supplier)	PEM Description	Quantity	PLGR PEM Cost	Equivalent HCEM Description	HCEM Cost
IC, RS-232 R/T	Linear Tech	SOIC, 16 pin	1	8.48	CERDIP, 16 pin	8.00
IC, RS-422 R/T	TI	SOIC, 14 pin	1	1.22	CERDIP, 16 pin	11.00
IC, A/D	National	Gull Wing, 20 pin	1	3.45	CERDIP, 20 pin	7.20
IC, Sw Reg.	Linear Tech	Gull wing, 5 pin	1	5.33	TO3	18.20
IC, Volt Det.	Maxim	SOIC, 8 pin	2	1.44	CERFP, 10 pin	30.66
IC, Volt Det.	Maxim	SOIC, 8 pin	1	1.62	CERDIP	3.06
IC, Volt Ref.	National (Motorola)	SOIC, 8 pin	1	.47	TO46	4.55
IC, Volt Ref.	National (Motorola)	SOIC, 8 pin	1	.53	TO46	4.55
IC, Op Amp	TI	SOIC, 8 pin	1	.61	CERDIP	2.89
IC, Volt Comp.	Philips (SGS-Thomson)	SOIC, 14 pin	1	.46	CERDIP, 14 pin	2.89
IC, Volt Comp.	Philips	SOIC, 14 pin	1	.46	CERDIP, 14 pin	2.89
IC, RS-232 R/T	Maxim	SOIC, 16 pin	1	1.30	CERDIP, 16 pin	7.56
IC, Volt Reg.	Maxim	SOIC, 8 pin	1	3.05	TO39	4.00
IC, SRAM	S-MOS (Hitachi)	SOIC, 32 pin	2	18.76	CERDIP	103.00
IC, Volt Ref.	National	SOIC, 8 pin	1	1.20	TO46	4.55
IC, Volt Reg.	National	SOIC, 8 pin	1	.90	CERFP, 10 pin	16.50
IC, Op Amp	National (Motorola)	SOIC, 8 pin	1	.23	CERDIP, 8 pin	3.50
IC, Comparator	National (TI)	SOIC, 8 pin	1	.21	CERDIP, 14 pin	.40
IC, CMOS dig	Philips (Motorola)	SOIC, 14 pin	1	.14	CERDIP, 14 pin	.80
IC, CMOS dig	Philips (Motorola)	SOIC, 14 pin	1	.14	CERDIP, 14 pin	.45
IC, CMOS dig	Philips (Motorola)	SOIC, 20 pin	1	.26	CERDIP, 20 pin	.80
IC, IF quantizer*	National	J-Lead, 44 pin	1	-	n/a	-
IC, AAMP2 $\mu$ P*	Rockwell	Gull Wing, 80 pin	1	-	n/a	-
IC, CMOS dig	Motorola	SOIC, 16 pin	2	.84	CERDIP, 16 pin	1.80
IC, 1 meg Flash	AMD (Intel)	J-Lead, 32 pin	2	9.90	CERDIP, 32 pin	130.00
IC, Sig Proc ASIC*	VLSI Tech. (LSI Logic)	Gull Wing, 208 pin	1	-	n/a	-
TOTAL:				\$61.00		\$369.25

\*Proprietary parts not included in cost analysis

### 3. COST COMPARISON

Table 1 compares the cost of the PEM selected with the cost of equivalent HCEM, based on purchasing experience for 10k quantities. In some cases, cost estimates were calculated for equivalent MIL parts because there are no readily available drop-in replacements. The equivalents are functionally identical, but are generally packaged as HCEM DIP, which are most readily available. Therefore, this cost comparison assumes that the HCEM alternative can be accomplished with through-hole technology.

### 4. OPERATING LIMITS OF THE SYSTEM

Table 2 shows the worst-case design operating limits, along with the test guidelines for specifying the limits. The PLGR program temperature requirements (-20°C to +70°C) did not present a problem for PEM used outside their specified temperature range. Thus, tests for temperature characterization, screening, or guard banding were neither needed, nor conducted on the incoming product.

TABLE 2  
PLGR Environmental Requirements

Environment	Requirement	Test Guidance
Temperature (operating)	-20°C to + 70°C	MIL-STD-810E, Method 501.3, Proc. I & II
Temperature (non-operating)	-57°C to +70°C	MIL-STD-810E, Method 501.3, Proc I & II
Humidity	RH 0% to 100% (non-precipitation)	MIL-STD-810E, Method 507.3, Proc. I
Vibration (sine wave)	1-inch double amplitude (5-7 Hz), 2.5G (7-40 Hz), 0.033-inch double amplitude (40-50 Hz), and 4.2 (50-500 Hz)	MIL-STD-810E, Method 514.4
Shock (general)	3 sawtooth 40G shocks of 11 msec duration along x,y,z, directions - a total of 18 shocks	MIL-STD-810E, Method 516.4, Proc. I
shock (transit drop)	Drop on face, edge and corner, 26 drops from a 48-inch height on a surface equivalent to floor of HMMWV	MIL-STD-810E, Method 516.4, Proc. I
Salt atmosphere	5% solution salt fog for 48 hours	MIL-STD-810E, Method 509.3, Proc. 1
Immersion	Immersion in water to depth of 1 m for 20 mins without leakage	MIL-STD-810E, Method 512.3
Fungus	Satisfies MIL-E-5400, paragraph 3.2.24.8	MIL-STD-810E, Method 508.4, Proc. IV

## 5. REQUIREMENTS ASSURANCE

A new 4.5-sigma enhanced-inspection program, developed specifically for the PLGR, uses SPC to estimate the variability of critical parameters in a sample lot. The incoming inspection data are used to estimate lot variability as well as specification compliance. If the lot fails specification-compliance, it is returned. If it is within specification limits, but the variability is under 4.5-sigma, the lot is accepted, but the supplier is contacted.

SPC-data monitor the supplier process control and are fed back to the supplier to improve the process. This lot-sampling approach is anticipated to result in lower cost and less handling damage, due to the elimination of 100% rescreens.

Since the PEM did not have special high-temperature use requirements, techniques specifically directed at assuring the PLGR PEM (*e.g.*, HAST or autoclave testing) were not performed. However, the PLGR was subjected to typical MIL program development testing to qualify the entire system. This included several tests:

### 5.1 First Article Testing

This phase included a TAAF step-stress test on 5 units. The TAAF, a combined environment test, included thermal cycling and random vibration stresses, which were increased in 7 steps, with the last 2 steps exceeding the specification limits. The thermal cycle was approximately 1 hour, with 10 minutes of random vibration applied each cycle. A 30°C overshoot was applied to speed up thermal stabilization. Table 3 summarizes the failure types and frequency; 8 failures were observed in 1793 accelerated, combined environment cycles. The step-stress TAAF test identified weaknesses in the following broad categories, in decreasing order of importance: component part, design, workmanship, and human/test equipment error, which were corrected. The failures observed were typical for new development and no problems unique to PEM were observed.

TABLE 3  
First-Article Reliability-Test Summary

Step	Completed Unit-Cycles	Thermal Cycle		Vibration	Failures	Description	Category
1	75	0	50	0.50	1	Frequency standard non-operational	Part
2	165	-5	55	1.25	1	Transistor overstress	Design
3	200	-10	60	2.00	1	Transistor overstress	Design
4	180	-15	65	2.75	1	Solder joint	Workmanship
5	300	-20	70	3.50	0		
6*	400	-25	75	4.25	2	1) Solder joint 2) Antenna	1) Workmanship 2) Part
7*	473	-30	80	5.00	2	1) Antenna 2) Chassis fracture	1) Part 2) Human error/test equipment
Total	1793				8		

\*Exceeds operating temperature limits

## 5.2 Reliability Demonstration Testing

This was done by the USG at the US Army Proving Grounds at Ft. Huachuca from 1993 September 12 to October 1. A combined environment-chamber reliability test (-20°C to +70°C thermal cycle and random vibration) was conducted, yielding a 11514 hour 'point-estimate' MTBF, and a 3845 hour lower '1-sided 80% s-confidence' MTBF—well above the 2000 hour Army requirement.

## 5.3 Operational Testing

The USG conducted operational tests at Army locations in Hawaii and Alaska from 1993 October - November. The demonstrated MTBOMF was 655 hours, and the projected MTBOMF was 2260 hours, based on an assumed 80% fix effectiveness for a failure pattern corrected by a design change. The Army requirement of 500 hours MTBOMF was satisfied by the PEM.

## 6. FAILURE DIAGNOSTICS METHOD

Failure diagnostics for the removed PEM, which provide part defect codes and initial failure symptoms, began with the observations provided by the manufacturing technician at the time of troubleshooting and repair, when the technician recorded whether part replacement fixed the problem. These service worksheets are reviewed to determine which PEM are primary failure analysis candidates. For example, the PEM are not subjected to further analysis for any of the following reasons:

- damaged in test at CACD;
- replacement parts damaged in repair during installation;
- replacement of a part did not fix the problem; subsequent replacements did fix the problem.

The parts selected for analysis are subjected to a failure analysis that includes:

- DC electricals at 25°C;
- acoustic microscopy;
- DC electricals over temperature;
- baking to electrically detect moisture problems;
- destructive physical analysis (decapsulation and internal inspection).

## 7. FAILURE ANALYSIS RESULTS

Of the 44 parts identified as candidates for destructive failure analysis, 3 were analyzed at the Army Research Labs. Since the electrical test method was incompletely developed at that time, analysis of these parts included decapsulation only. One part failed due to electrical overstress; no visual internal defects were observed on the other two.

Acoustic microscopy analysis carried out on 13 samples showed appreciable delaminations, some die attach disbonds, 1 popcorn-crack almost to the surface, and 1 popcorn-crack to the surface. The remainder of the failure analysis, including additional electrical tests (as necessary) and decapsulation, is in progress. However, we do not yet know whether the defects detected by acoustic microscopy were caused by primary failure mechanisms or by testing methods. For example, the part with the popcorn crack to the surface (a 208-pin ASIC) was removed using a hot-air reflow machine, a process that could have caused the crack.

Four parts were completely analyzed, per the failure analysis process outlined at the CACD failure analysis laboratory. Three of these passed electrical tests over the temperature range and were categorized as not verified. One part failure was verified to be caused by electrical overstress. All parts will be analyzed by the completion of this study.

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